SC Magnets in High Radiation Environment at Supercolliders

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- Radiation issues for various machine configurations
  - LHC IR Upgrade
  - SLHC
  - VLHC
- Radiation dose limits for various materials
- Radiation heat-loads in SC magnets
- Cryogenic implications

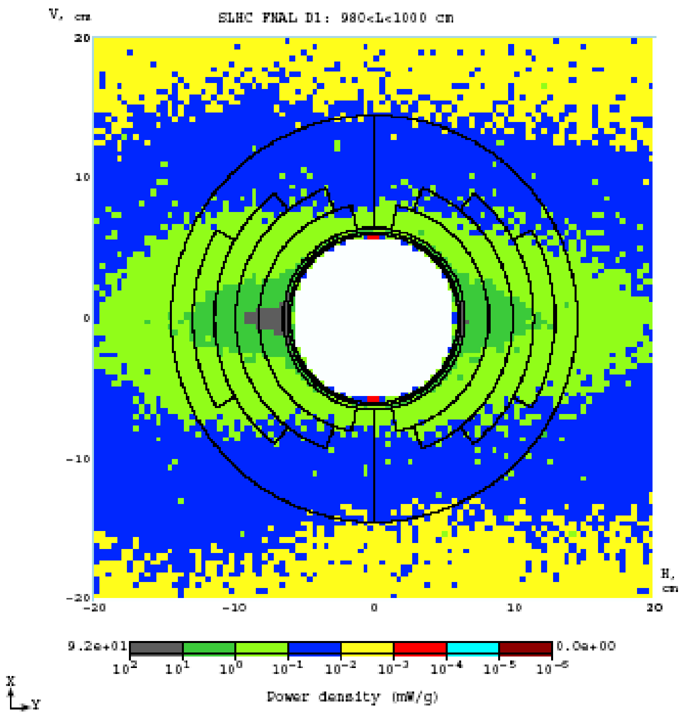
Radiation Loads in SC Magnets

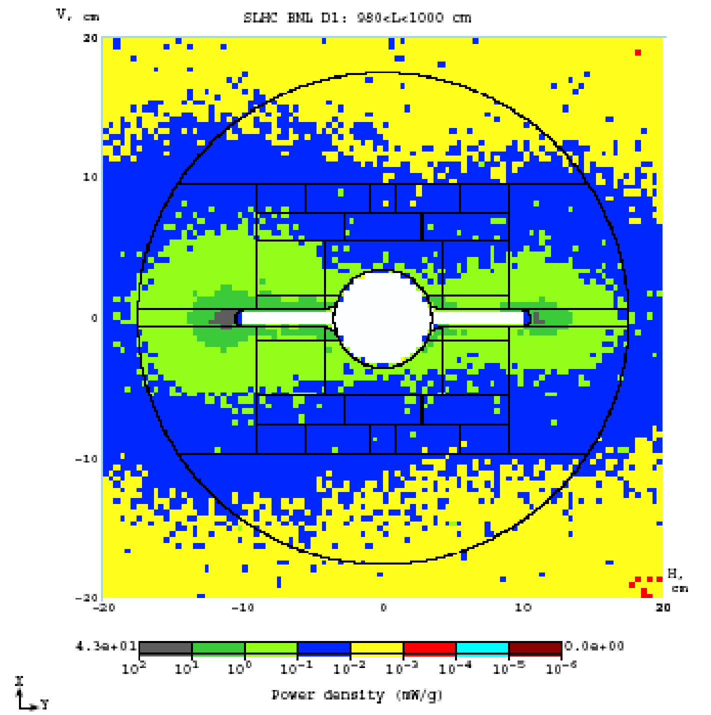
- Main ring magnets ~ total beam energy 0.35 GJ (LHC), 1.1 GJ (SLHC), 3.2 GJ (VLHC) and beam loss rate (electron clouds, collimation efficiency)
- IR magnets ~ luminosity (upgrade energy, not luminosity)

Radiation Issues

- Quench stability (peak power density, heat transfer): OK at LHC and SLHC (block coil dipole-first, not Cosθ!) with appropriate protection system
- Dynamic heat loads: OK at LHC (30 W/quad) and challenging at SLHC (3.5 kW in dipole-first)
- Radiation damage: 10-yr dose is 20 (LHC) to 50 MGy (SLHC block coil D1, not Cosθ!) averaged over cable height; neutron fluence seems to be not an issue 10^{16} to $4x10^{16}$ cm^{-2} over 10 years ($3x10^{17}$ at SLHC Cosθ)
- Residual dose rates - Hands-on maintenance: OK at LHC and challenging at SLHC

SLHC Dipole-First





Peak power density is 49 mW/g in copper spacer and 13 mW/g in SC coil (left) and only 1.1 mW/g in the SC coils of block-type dipole (right). Total power dissipated in the dipole is 3.5 kW in either design.

10-year Peak Dose & Fluence in IR

Peak dose D and neutron fluence $F_{>0.1\ MeV}$ in inner triplet SC coils accumulated over first 10 "LHC" years (=5×10^7 sec). D (MGy/yr) = 50 ε (mW/g). Current designs. Very preliminary for VLHC-1 and VLHC-2.

Machine	Component	D (MGy)	$F_{>0.1\ MeV}$, 10^{16} cm^{-2}
LHC	Quad Q2B	22.5	1.04
LHC-2	Quad Q2B	45.0	2.08
SLHC	Cosθ D1	650	30
SLHC	Block coil D1	55.0	2.54
VLHC-1	Quad Q2B	$\sim$30	$\sim$1.5
VLHC-2	Quad Q2B	$\sim$84	$\sim$4

Materials

- **Superconductor (Nb_3Sn)**
- **Insulation**
- **Copper**
- **Structural materials**

General limits for Nb_3Sn

- **T_c goes to 5 K – 5 x 10^{19} n/cm^2**
- **I_c goes to 0.9 I_{c0} at 14T – 1 x 10^{19} n/cm^2**
- **B_{c2} goes to 14T - 3 x 10^{18} n/cm^2**

- Neutron fluence at supercolliders is low enough that this isn't of too much concern

BUT

- **NOTE: $E_n < 14$ MeV**
- Damage increases as neutron energy increases

General Radiation Dose Limits

Material	Useful limit (MGy)
Copper	$>10^4$
Iron, Stainless steel	$>>10^3$
Ceramics	$>10^3$
Organics	$\sim 10^2$

(most sensitive properties)

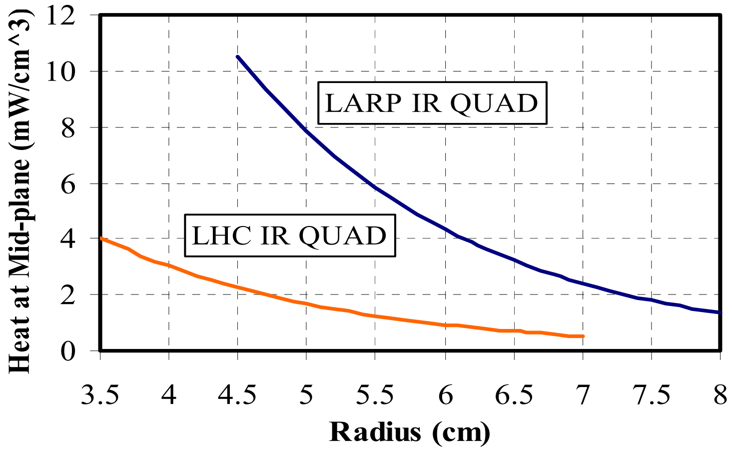
R&D Needed

* Need local radiation field at sensitive points
  - at position of highest shear stress
  - at position of peak compression
  - at position of peak field

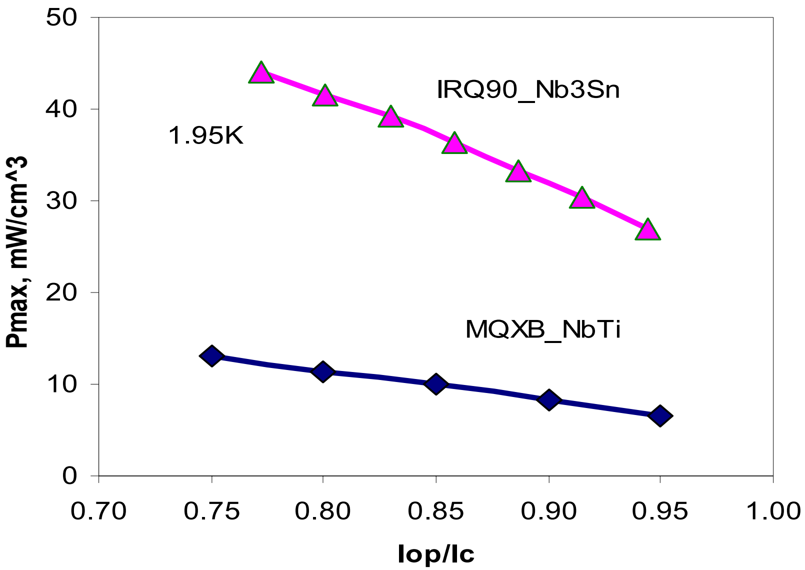
* Need data at reactors and at energies greater than 14 MeV on
  - critical materials
  - safety factors for materials
  - composite structures

LARP IR QUAD Heat Loads

- Heat-loads as a function of radius and angle were first evaluated

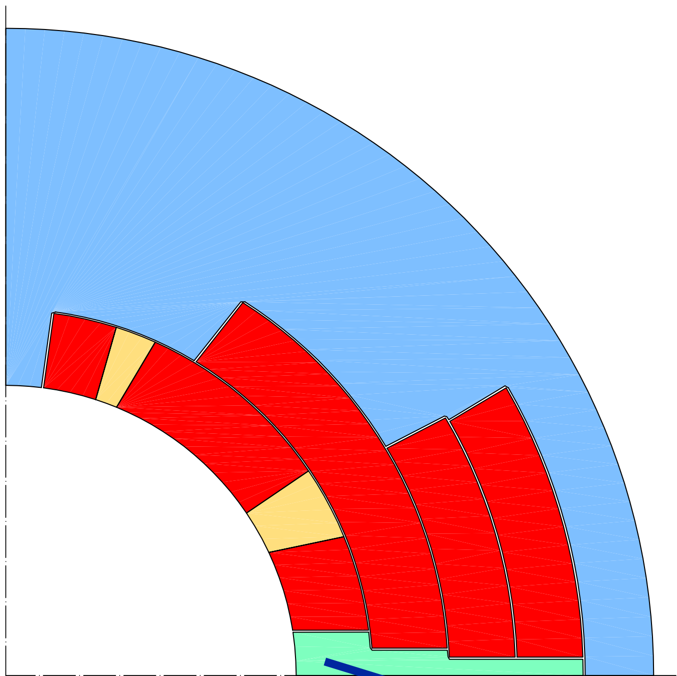


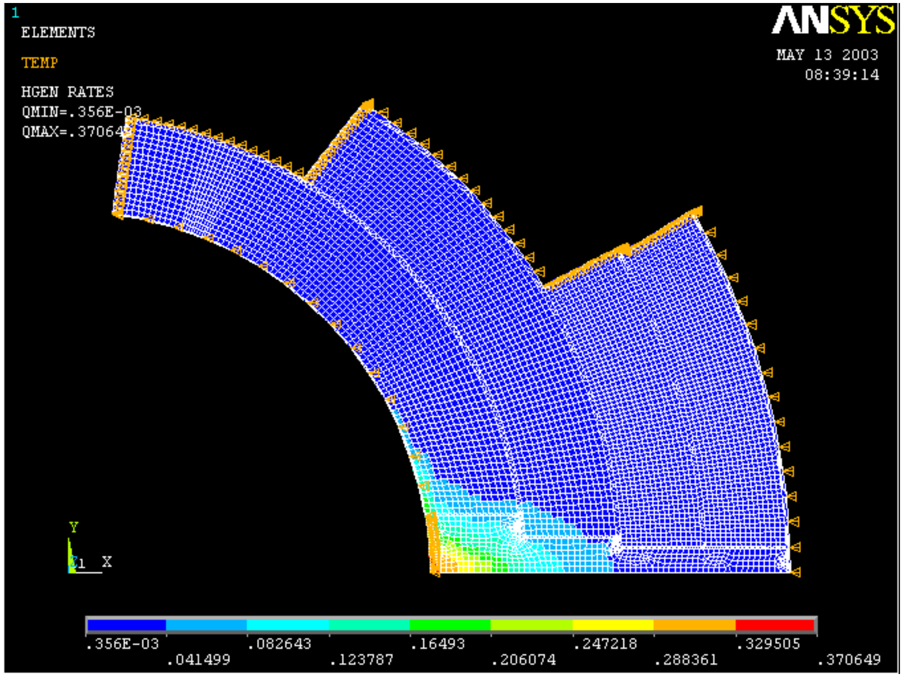
- Nb_3Sn magnet designed with 20% quench margin can tolerate up to 40 mW/cm^3 of peak power dissipation in the mid-plane turns



SLHC *Dipole-First* Heat Loads

Applied heat loads on coil elements in mW/mm³





Copper spacer

$$Q_{peak\_spacer} = 49\ mW/g;\quad Q_{peak\_coil} = 13\ mW/g = 30 \times Q_{peak\_MQXB\_coil}$$

SLHC *Dipole-First* Thermal Analysis

Cooling Conditions	Peak Temperature
External	27.7 K
External + Mid-Plane	24.8 K
External + Inter-Layer	11.3 K
External + Inter-Layer + Mid-Plane	11.3 K
Porous inner bore + All the above	7.0 K

Note: Calculations based on boundary conditions that sets coil perimeter at 1.9 K

Cryogenic Considerations

- Perspective from LHC point
  - Accelerator cryoplant: 4 x 18 kW = 72 kW @ 4.5 K
  - Beam screen requires 1.7 W/m between 4.6 and 20 K (1.7 W/m x 27 km = 45.9 kW)
  - Remaining ~ 26 kW mostly goes to 1.9 K cooling
  - 26 kW converts to ~ 11 kW @ 1.9 K due to lower thermodynamic efficiency (check)
  - Average 1.9 K heat load on LHC accelerator magnets < 0.4 W/m
  - IR 110 W/4 quads (total = 440 W @ 1.9 K)

Cryogenics for Luminosity Upgrade

- Luminosity upgrade from 10^{34} to 10^{35} results in increase in beam screen heat load from 1.7 W/m to 15 W/m
  - Increase total screen load to 405 kW @ 4.6 to 20 K!
  - Impact on 1.9 K load on main ring dipoles (0.4 W/m to ~ 0.8 W/m) or ~ 22 kW @ 1.9 K
  - Can be handled by changes in cooling configuration
- Dipole-First
  - 3.5 kW x 4 dipoles = 14 kW (30 times LHC) at 1.9 K, 4.5 K, higher T?
- Options to consider
  - Operating magnets at higher T, but can they be cooled & stabilized?
  - Use of HTS would help with overall power requirements if they could operate ~ 20 K or higher.

Summary

- Generate table
  - Characterize various IR designs in terms of radiation environment
    - Peak energy deposition
    - Fluence
    - Dose
    - Cryo load
  - Define material properties and acceptable design criteria for given dose

- Survey of fusion program results
  - Identify relevant information (no duplication)
  - Identify areas for focus
    - Nb_3Sn behavior in LHC IR radiation field
      - Develop appropriate tests (magnetization measurements in lieu of direct Jc)

- Identify existing rad hard materials for incorporation into magnet programs
- Focus R&D on what is left